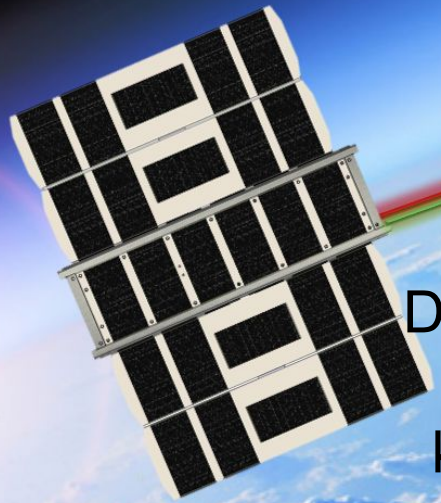
Applications of CubeSat Laser Communication Systems to Atmospheric Sensing and Astrophysics



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So, we've got CubeSat crosslink lasercom...

- Sure, you can use it to coordinate multiple CubeSats with precision ranging:
  - Interferometry!
  - Distributed and synthetic apertures!

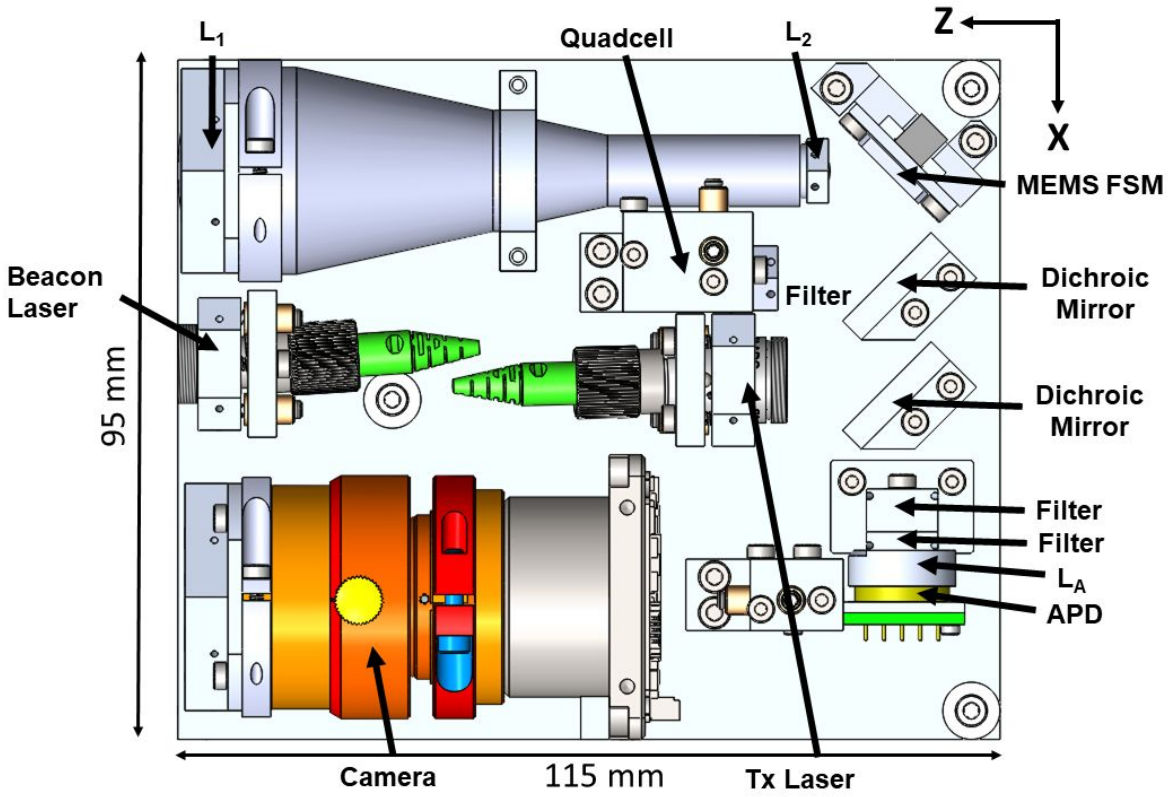
- But, here we will talk about two uses of lasercom technology for planetary (and exoplanet) exploration:

  1) Atmospheric sensing: laser occultation of planetary atmospheres

  2) Astrophysics: formation-flying laser guide star to see fainter objects with large telescopes

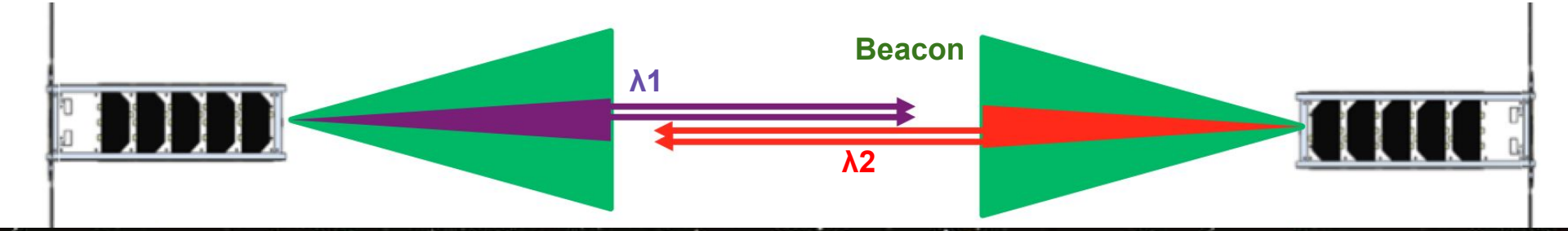
CLICK: CubeSat Lasercom Infrared CrosslinK

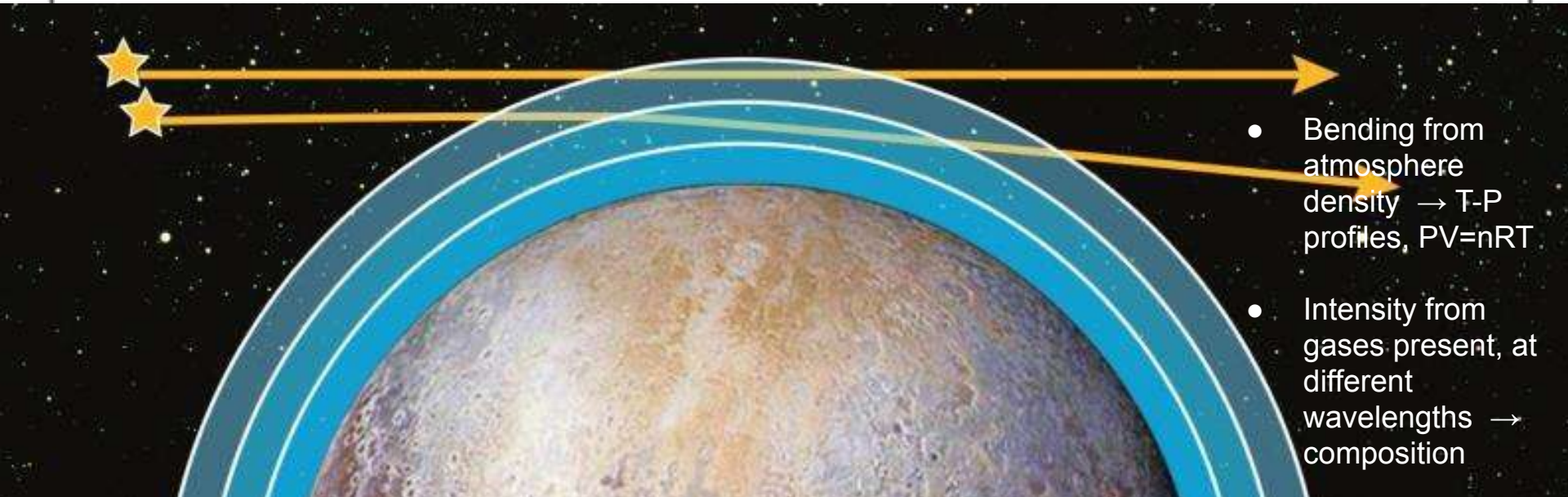
- MIT, UF, NASA
- < 1.5U module in 3U CubeSats
  - CLICK-A: downlink
  - CLICK-B/C: crosslink
- Full-duplex crosslink
  - >20 Mbps at <30 W
  - 25 km to 580 km
  - Beacon 500 mW, 0.75 deg FWHM
  - Data 200 mW, 14.6 arcsec FWHM
- Precision ranging
  - ~10 cm



1) Atmospheric Sensing: Laser Occultation

Laser Occultation

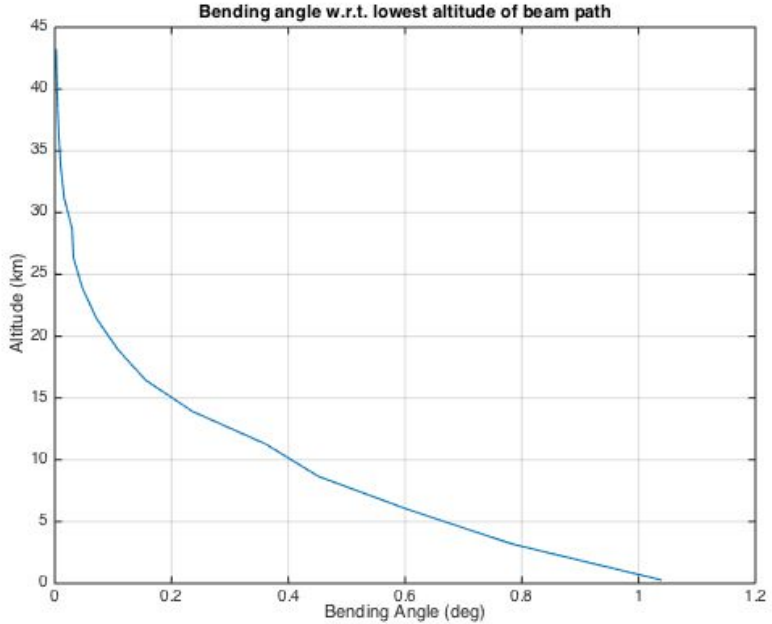




- Bending from atmosphere density → T-P profiles, PV=nRT
- Intensity from gases present, at different wavelengths → composition

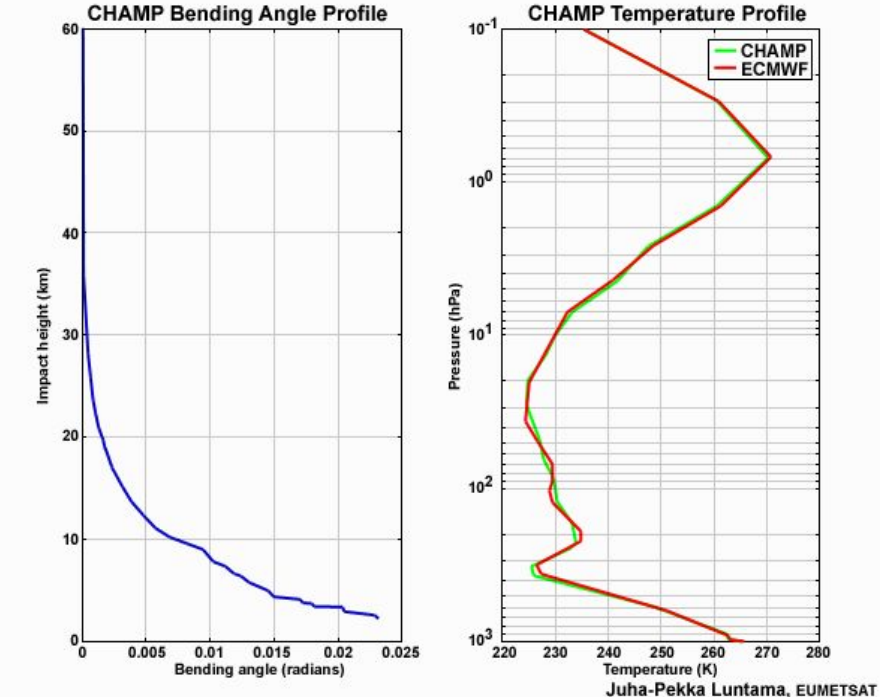
Bending Angle → Temp-Pressure profiles

Example lasercom bending angles



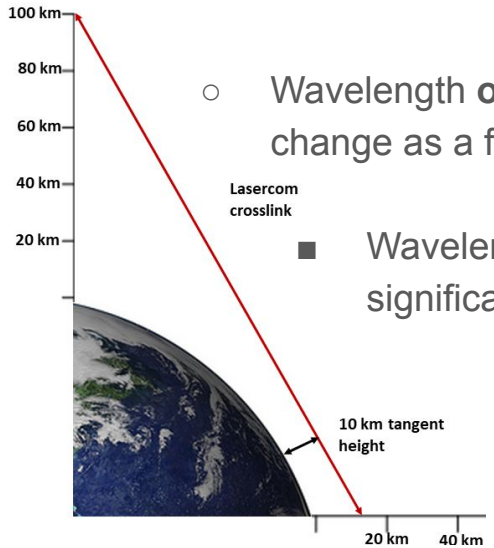
Fine pointing stage can record bending angle.
MEMS steering mirror resolution: 0.137 arcsec

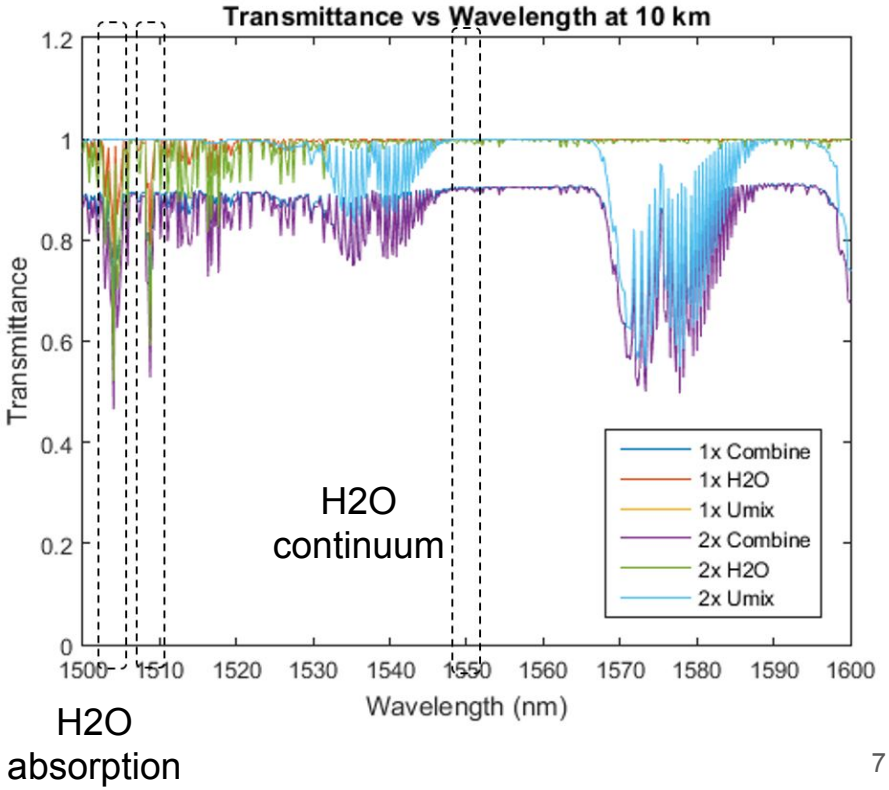
GPS Radio Occultation Earth
Bending Angle (blue) and T-P Profile



Differential Absorption for Composition

- Retrieve composition using multiple wavelengths
- Water vapor modeled for crosslink
  - Wavelength **on continuum**, little change as a function of composition
    - Wavelength **in absorption**, has significant change





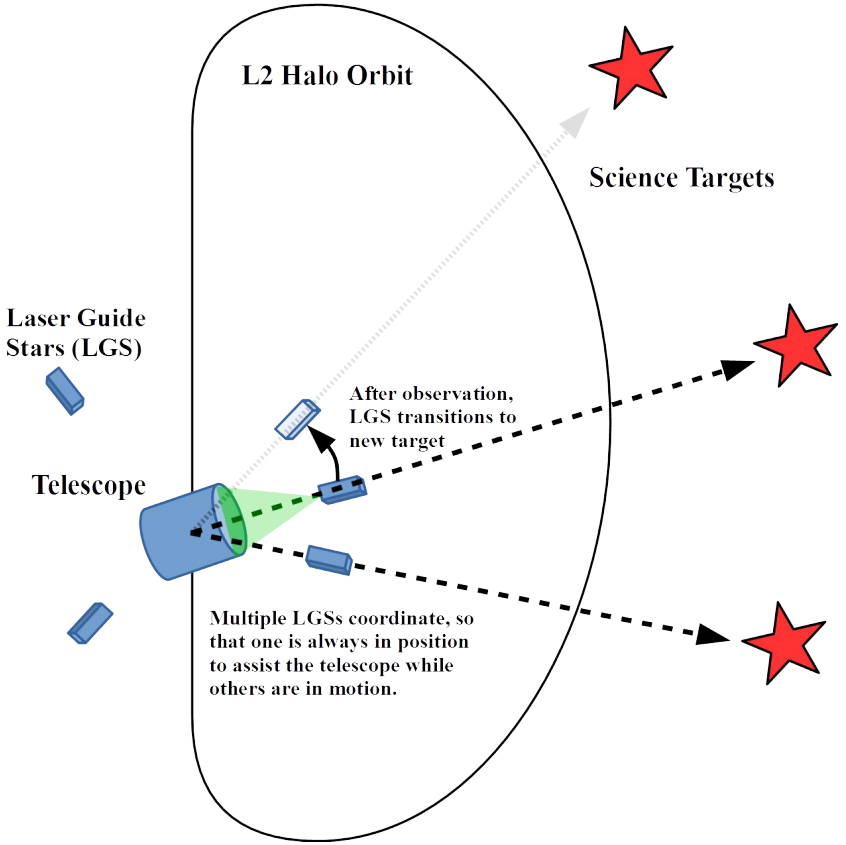
Laser Guide Star

- Use a formation-flying CubeSat with laser transmitter to provide more photons to a telescope Adaptive Optics system (wavefront sensing and control)
- Allows faster and better correction of optical aberrations → improved images
- Relevant for exoplanet and solar system planet imaging as well as other targets

2) Astrophysics: Formation-flying laser guide star to see fainter objects

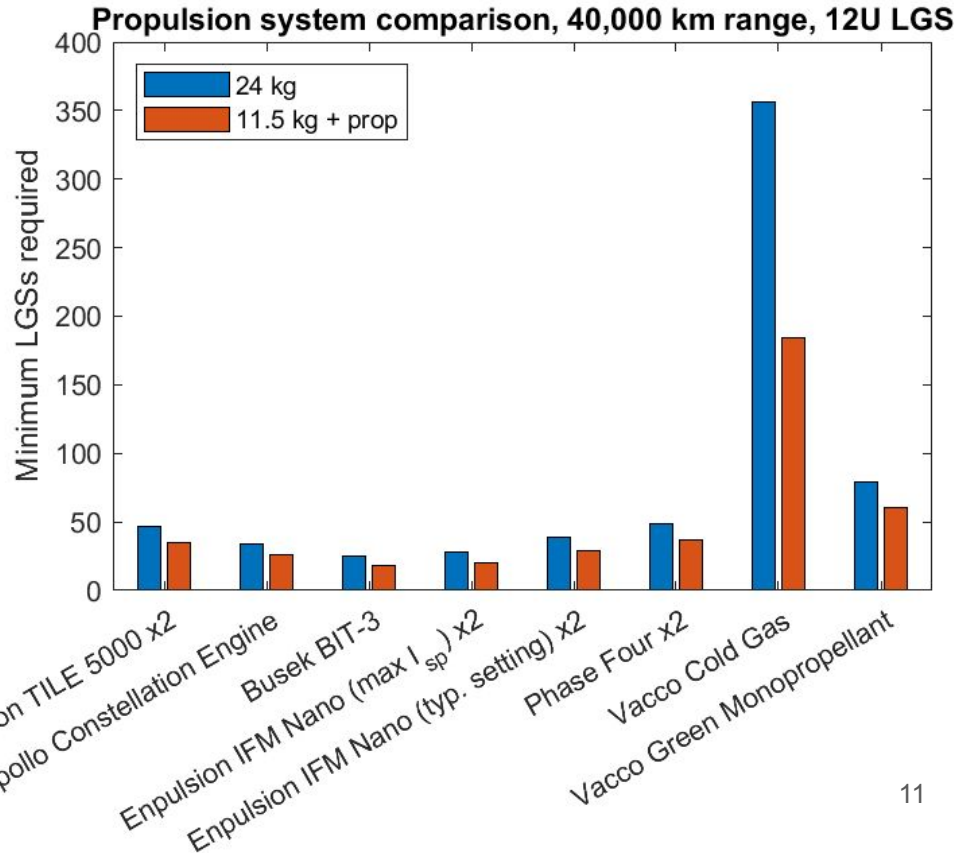
Laser Guide Star

- LUVOIR segment stability must be ~picometers for exoplanet imaging
  - Hard/expensive/impossible(?) to build
- Natural guide stars aren't bright enough to support segment control
  - And are not necessarily near targets
- A formation-flying CubeSat with laser transmitter is bright enough…optical requirements established in Douglas et al. 2019 [1].



Formation Flying Propulsion Options

- LUVOIR wants to observe a star every ~day, so we need multiple LGS spacecraft to keep pace.
- Multiple options now for electric propulsion with high dV.
- Trade ongoing: range to telescope. Closer means fewer LGSs, but more complicated WFCS.
- Study ongoing: thruster reqs for multi-day observations.



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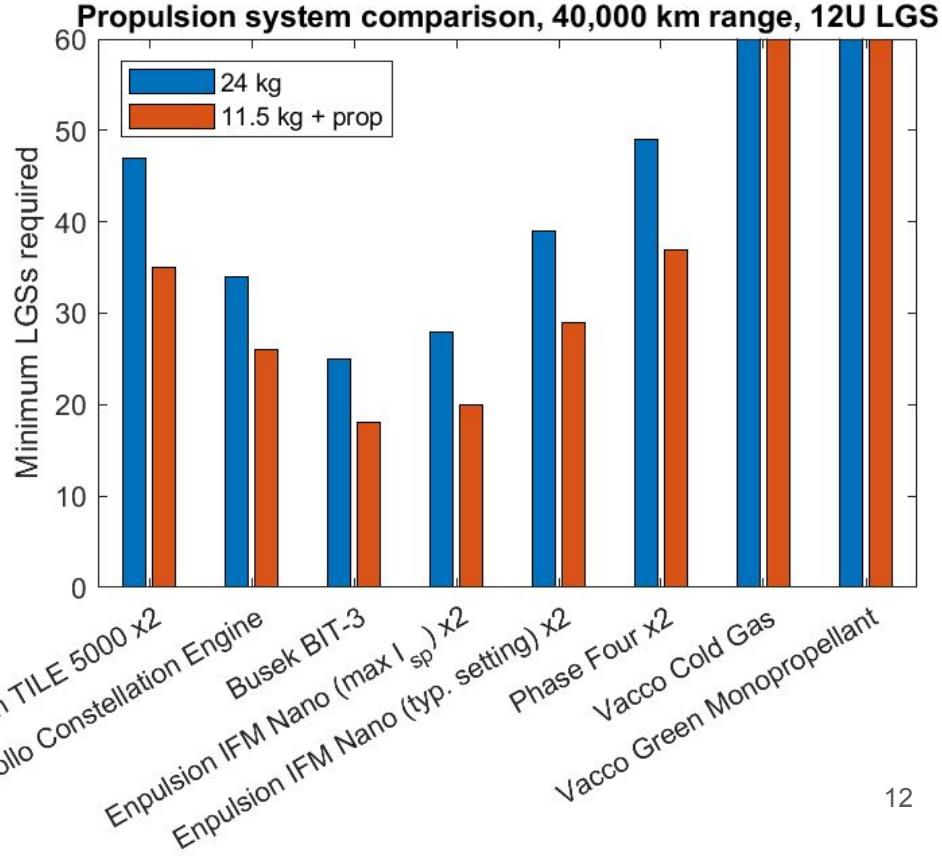
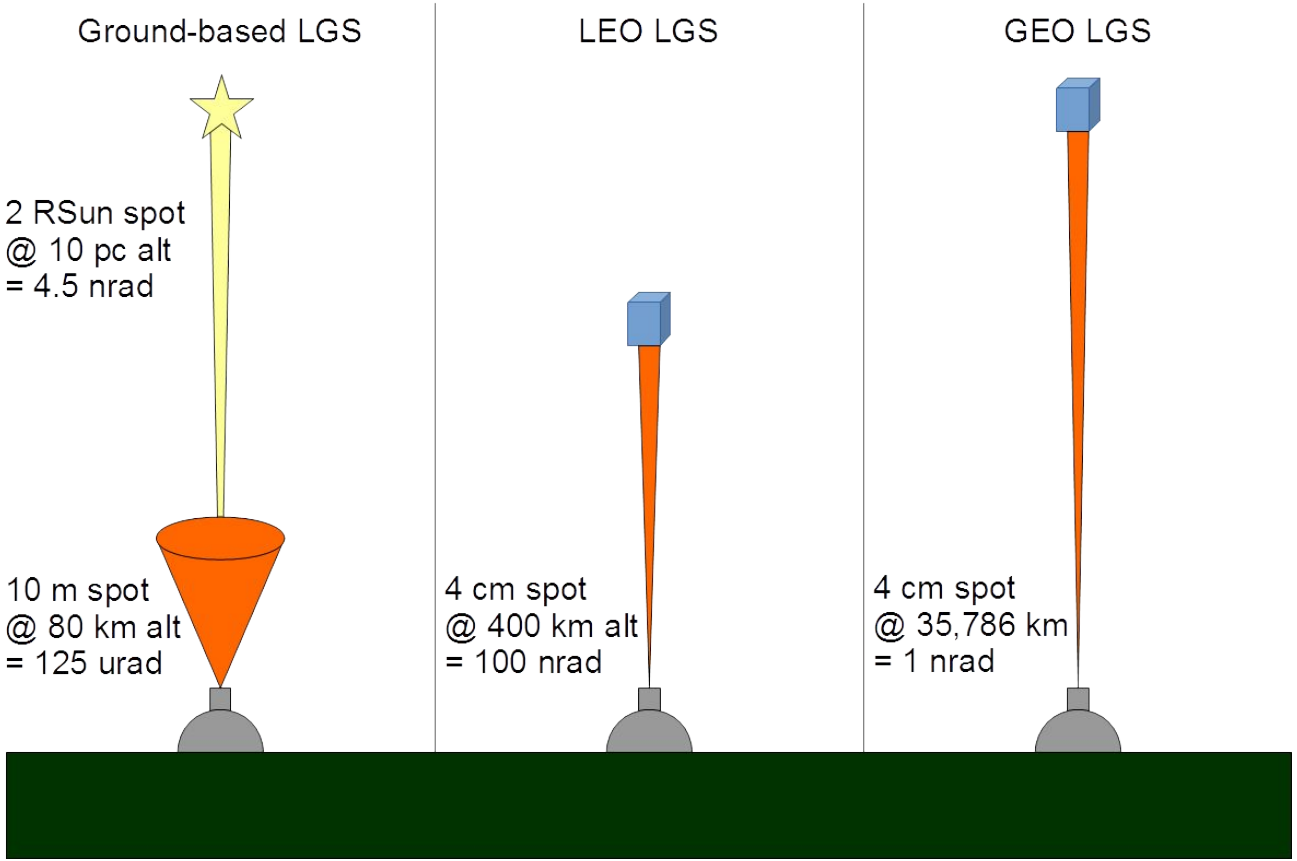


Laser Guide Star

- GEO to ground lasercom is TRL 9
- But few telescopes track LEO
- Vmag of lasercom terminals is **-5**



Summary

- NASA can leverage lasercom technology for planetary exploration
- CubeSat lasercom is intended to enable coordination for interferometry, synthetic aperture radar, and distributed imaging applications
- But also! Atmospheric composition, temperature-pressure measurements
- But also! Imaging fainter objects with astronomical telescopes (in space and on Earth)
- Strongly encourage Earth-orbit technology demonstrations (also useful for Earth) and then incorporation into future solar system exploration missions

References

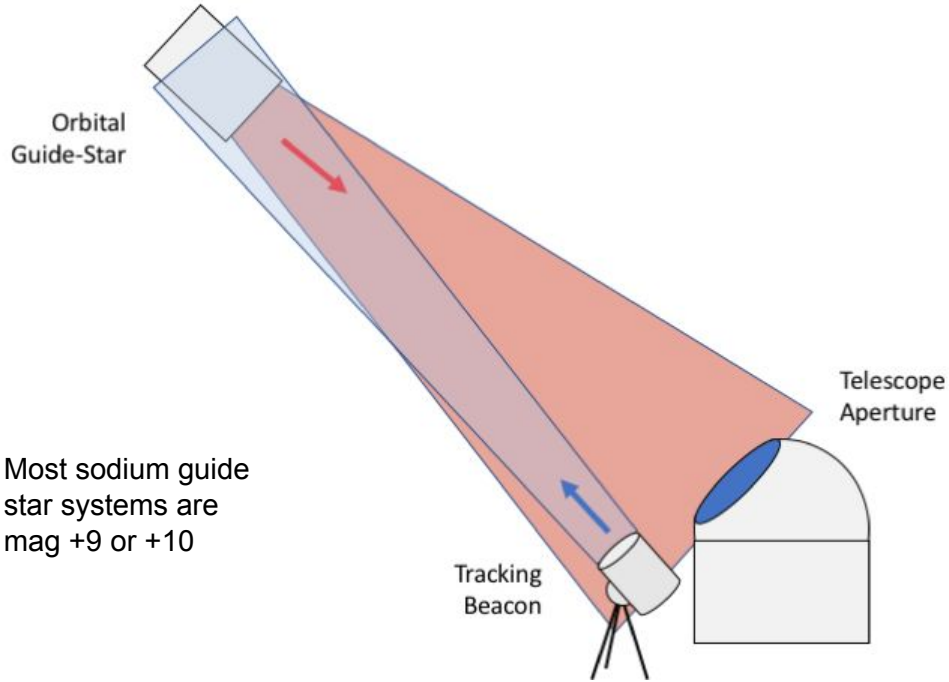
1. Douglas, E. S., Males, J. R., Clark, J., Guyon, O., Lumbres, J., Marlow, W., and Cahoy, K. L., “Laser Guide Star for Large Segmented-aperture Space Telescopes. I. Implications for Terrestrial Exoplanet Detection and Observatory Stability,” *The Astronomical Journal*, vol. 157, Jan. 2019, p. 36.

Backup: Abstract as Submitted

We discuss three different applications of CubeSat lasercom systems: 1) CubeSat lasercom systems can enable multi-spacecraft coordination by providing precision ranging and high data rate intersatellite links. 2) CubeSat laser crosslinks can enable concurrent measurements of atmospheric composition, temperature, pressure, and wind. 3) CubeSats with laser transmitters can be used as bright satellite laser guide stars for either ground or space-based telescopes that use adaptive optics, improving their ability to image dim targets and relaxing stability requirements on segmented apertures.

Backup: Satellite Laser Guide Star Example: Use existing GEO ComSat Terminal TDP1 on Alphasat

Parameter	Nominal Power	Max. Power
Transmit power (W)	0.1	5
Wavelength (nm)	1064	
Beam divergence (urad)	7.1 (half-angle) (1.5 arcsec)	
Range (km)	35,786	
Spot diameter (m)	508	
Throughput	10%	
Received flux (W/m^2)	4.9×10^{-8}	2.5×10^{-6}
Received flux ($phot/s/cm^2$)	2.6×10^{7}	1.3×10^{9}
Received magnitude	-4.6	-8.9
Required mag	< 8	
Margin factor	120,000	5,900,000



Most sodium guide star systems are mag +9 or +10